UPPER METER PROCESSES: SHORT WIND WAVES, SURFACE FLOW, AND MICROTURBULENCE

Bernd Jähne
Physical Oceanography Research Division 0230
Scripps Institution of Oceanography
La Jolla, CA 92093-0230
phone: (619) 534-6860, fax: (619) 534-8509, e-mail:bjaehne@ucsd.edu
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LONG-TERM GOAL

The primary goal of this project is to advance the knowledge of small-scale air-sea interaction processes at the ocean surface, focussing on the dynamics of short waves, the surface flow field and the micro-turbulence. A better understanding of the physics of these waves will also benefit the study of electromagnetic backscattering from the sea surface.

SCIENTIFIC OBJECTIVES

The technological objective of this research project is to provide optical instrumentation for the high-resolution spatiotemporal measurement of short wind waves, the surface flow, and the micro-turbulence in the field. The newly developed instruments will be used to acquire statistical data such as joint height/slope/curvature probability density functions and mean square slopes; image sequences of the temperature fluctuations for the determination of the surface velocity field; and image sequences of the water surface gradient. These data yield directional wavenumber-frequency spectra, reconstruction of the ocean surface fine structure, and time sequences of the velocity field at the air-sea interface.

The scientific objective is to combine the data from these instruments with meteorological ground truth to obtain a better insight into the dynamics of the interaction between short wind waves and the turbulent drift layer at the ocean surface. This is achieved by studying wave number spectra of short waves as a function of wind stress, surface films, surface currents, and swell.

APPROACH

Two different types of optical field instruments have been developed, in order to obtain these kind of data. The Height Slope Curvature Instrument (HSCI) provides time series of a variety of statistical wave parameters. A setup with two cameras and two light sources is used to observe the reflections from slightly different viewpoints. The slope statistics of short waves can be inferred from number, size, and total intensity of the measured reflexes. The form of the reflexes in terms of the deformation of the geometry of the light source yields information about the curvature of the observed area. The other field instrument is a drifting buoy that carries an improved wave slope imaging system (ISG) and an infrared imaging system for the simultaneous measurement of the water surface gradient (wave slope) and the temperature fluctuations.

WORK COMPLETED

In the course of the last three years, we have developed field versions of the HSCI and the ISG. On several occasions these prototypes were tested in the laboratory, off the Scripps Pier, and from FLIP. During the MBL ARI West Coast Experiment in April/May 1995 and the North

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Atlantic CoOP cruise in June/July 1997, the instruments were deployed in the open ocean. First wave number spectra were measured successfully and have been published. These data show that it is possible to obtain wave number spectra of small-scale waves in the field over short periods of time. From the experiences with the prototype, a second-generation wave-imaging buoy has been designed within the last year. It incorporates a camera system for the imaging of the water surface gradient, a high resolution infrared camera, and a carbon dioxide laser for the measurement of the local heat transfer velocity, the near surface turbulence, and the surface drift within the footprint of the imaging slope gauge. A modified LED light source (consisting of over 16,000 LED) and the use of four CCD cameras allows for wave slope imaging during daylight conditions. This is a major advantage over the prototype, which could only be operated during the night.

RESULTS

For the first deployments of the wave imaging buoy from the R/V Oceanus the during the North Atlantic CoOP cruise in June/July of 1997, only the infrared imaging system was fully functional. Overall, however, the instrument showed improved performance with regard to stability and minimization of wave field disturbance and will allow for systematic studies of the wave number spectra and the modulation of short wind waves by long waves in the next two years. With the HSCI we were able to collect an extended data set of reflex image sequences.

The comparison of the wave number spectra of short wind waves from the lab and the field shows large scatter of the spectral densities at low wind speeds. This can be attributed to the effect of surface films and background wave conditions. For higher wind speeds the dependence of the spectral density on the friction velocity is found to vary linearly with the wave number for short gravity waves to almost cubic for capillary waves. In previous field investigations by other investigators (Hara, et al., 1994 and Hwan*g*, et al., 1996), spectral densities at low wind speeds were significantly higher than observed in the laboratory. As one possible explanation they offered the fluctuating component of the wind field, which is high in the field but low in the laboratory. This comparison was, however, based only on a limited set of laboratory using the data of Jähne and Riemer (1990) from the Delft wind wave flume at 100 m fetch. Meanwhile, however, we have a much more detailed data collection including measurements form the Delft, Marseille, Heidelberg, and Wallops facilities. The data show that the 1988 Delft data have the lowest spectral densities. Especially the spectral densities in the Heidelberg facility with unlimited fetch are a factor of 2 – 4 higher at low wind speeds and thus are much closer to the field data. This suggests another explanation for the higher spectral densities of short waves at low wind speed under oceanic conditions. Since the pioneering experiments of Cox (1958), it is known that steep short gravity waves can generate parasitic capillary waves even without wind. Therefore, under oceanic conditions, parasitic capillary waves should be produced even more frequently.

IMPACT/APPLICATION

We have shown that the new instruments are field-suitable and provide the kind of high resolution, spatiotemporal data necessary to study intermittent processes at the air-sea interface. The data acquired during MBL ARI 1995, during the CoOP cruise 1997, and future measurements from the SIO Marine Observatory will allow for a systematic study of the parameters influencing the wave number spectra of short wind waves. As demonstrated by the recent results, the quantitative comparisons with our detailed measurements of wave number spectra in laboratory facilities under controlled conditions will be an invaluable asset for the understanding of the wave number spectra measured at sea.

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Figure 1. Dependence of the Saturation Spectral Densities on the Friction Velocity in Air for Different Wavelength

The new wave imaging buoy permits the study of the interaction of surface turbulence and surface waves, by using the wave slope imaging technique in combination with the infrared imaging of the water surface. It is also suitable to measure the modulation of short waves by long waves. Currently, the HSCI is being installed on the Scripps Pier for longterm monitoring of mean-square-slope. In the future, it is planned to deploy the wave imaging buoy in the vicinity of SIO Marine Observatory.

TRANSITIONS

The IR surface turbulence imaging technique and the wave slope imaging gauge technique are now being used by Prof. W. K. Melville (Scripps Institution of Oceanography) in an NSF project to study generation and evolution of Langmuir circulation in the laboratory. A *1–D* version of the imaging slope gauge has been installed at the air-sea interaction facility Wallops Island, VA. It is used by Dr. N. E. Huang (NASA/Goddard Space Flight Center) and Dr. S. R. Long (NASA/Wallops Flight Facility) in NASA projects on the generation of wind waves and wave-current interaction.

RELATED PROJECTS

In collaboration with Dr. J. C. West (Oklahoma State University), profiles of the alongwind surface slope for different wind speeds have been used as realizations to compute the electromagnetic backscattering from wind-roughened water surfaces. It is planned to apply this analysis to reconstructions of the water surface in two dimensions. The activities within the MBL ARI are closely related to the ONR research project “Local Measurements of the Air-Sea Gas Transfer Rate” and the NSF CoOP project “Air-Sea Gas Exchange in Coastal Waters.” Both projects focus on the air-sea gas exchange at the interface and thus fit well into the context of the MBL ARI. The NSF CoOP experiment is performed in cooperation with Dr. E. Bock (Woods Hole Oceanographic Institution). In cooperation with the image processing group of the PI at the Interdisciplinary Center for Scientific Computing (University of Heidelberg, Germany), new algorithms are being developed for the local analysis of the wave slope and surface flow image sequences.

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